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Is particulate air pollution at the front door a good proxy of residential exposure?☆

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ABSTRACT

The most advanced epidemiological studies on health effects of air pollution assign exposure to individuals based on residential outdoor concentrations of air pollutants measured or estimated at the front-door. In order to assess to what extent this approach could cause misclassification, indoor measurements were carried out in unoccupied rooms at the front and back of a building which fronted onto a major urban road. Simultaneous measurements were also carried out at adjacent outdoor locations to the front and rear of the building. Two 15-day monitoring campaigns were conducted in the period June–December 2013 in a building located in the urban area of Bologna, Italy. Particulate matter metrics including PM2.5 mass and chemical composition, particle number concentration and size distribution were measured. Both outdoor and indoor concentrations at the front of the building substantially exceeded those at the rear. The highest front/back ratio was found for ultrafine particles with outdoor concentration at the front door 3.4 times higher than at the rear. A weak influence on front/back ratios was found for wind direction. Particle size distribution showed a substantial loss of particles within the sub-50 nm size range between the front and rear of the building and a further loss of this size range in the indoor data. The chemical speciation data showed relevant reductions for most constituents between the front and the rear, especially for traffic related elements such as Elemental Carbon, Iron, Manganese and Tin. The main conclusion of the study is that gradients in concentrations between the front and rear, both outside and inside the building, are relevant and comparable to those measured between buildings located in high and low traffic areas. These findings show high potential for misclassification in the epidemiological studies that assign exposure based on particle concentrations estimated or measured at subjects' home addresses.

1. Introduction

Air pollutants, and airborne particles in particular, pose significant risks to human health (REVIHAAP, 2013). A body of evidence has been accumulating over the last few decades on the effects of air pollution on cardiovascular and respiratory diseases, but there is still considerable uncertainty about the mechanisms of action linked to the health effects and about which physical and/or chemical characteristics of particulate matter (PM) are most important as determinants of health effects (Harrison and Yin, 2000; Kelly and Fussell, 2012).

A key point in assessing the health effects of air pollution is contrasting exposure between people residing in different cities

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(Pope et al., 2009; Dockery et al., 1993) or different areas within the same city and its surroundings (Raaschou-Nielsen et al., 2013; Beelen et al., 2014). Differences in exposure for people residing in urban areas are mainly related to differences in proximity to traffic sources and the most recent and advanced epidemiological studies, especially those devoted to long term and traffic-related health effects (Hampel et al., 2015; Wang et al., 2014), assign exposure based on outdoor concentration of air pollutants measured or estimated at the front door. In this respect, Land Use Regression Models and Dispersion Models provide comparable performance (de Hoogh et al., 2014; Beelen et al., 2010) and have been demonstrated to be effective tools to improve exposure assessment compared to the use of data from fixed site monitoring stations. Nitrogen dioxide and particle concentration (usually ultrafine particle number or particles with aerodynamic diameter below 10 μm – PM_{10} – or particles with aerodynamic diameter below 2.5 μm – $PM_{2.5}$) are the most common parameters used as air quality indicators.

While a number of studies have investigated spatial variations of air pollutant concentrations between traffic and urban background sites (Boogaard et al., 2011; Naser et al., 2008; Harrison et al., 2004) and in specific locations, such as building-free areas near highways (Patton et al., 2014; Zhu et al., 2002) or inside street canyons (Zhou and Levy, 2008), only very few studies have addressed specifically the issue of the differences between the concentrations of air pollutants at the front and back of buildings next to busy streets (Weber and Weber, 2008; Hitchins et al., 2002). Weber et al. found differences in particle mass and number concentrations between a busy urban street canyon and an adjacent backyard using optical particle counters. Higher concentrations in the canyon of on average 30% for PM_{10} and 22% for PM_1 were found within the street canyon. On the contrary Hitchins et al. found no significant gradients from the front to the rear of the building for $PM_{2.5}$ and submicrometer particle number concentrations considering three low-rise buildings at a distance between 11 and 75 m from roads.

The main goal of this paper is to investigate which particle metrics measured at the front door can be used as proxies of residential exposure. More specifically, we would like to investigate how large are the errors in assigning the same exposure to individuals residing in the same building near major roads. This is a key point in epidemiological studies because these individuals represent the very important subpopulation of highly exposed subjects. This work is part of a series of monitoring campaigns planned within the “Supersito” project (http://www.arpa.emr.it/supersito) aimed at assessing the variability of exposure within urban areas with a special emphasis on various PM metrics (Zauli Sajani et al., 2015).

2. Methods

2.1. Study design

To achieve the study aims, two main methodological options were selected a-priori.

The first is the choice of going beyond the mere comparison of front/back outdoor particle concentrations by including analyses indoors, where population exposure mostly occurs.

The second is the choice of monitoring uninhabited indoor environments. The main reason for this choice was related to the fact that many studies suggest that particles of outdoor and indoor origin have different physical and chemical characteristics (Brown et al., 2008) and probably can also cause different health effects (Zhou and Levy, 2013; Ebelt et al., 2005). In fact, indoor exposure to particulates comes from particles of outdoor origin on which additive contributions of indoor-generated particles arising from specific indoor sources superimpose (Urso et al., 2015; Fuller et al., 2013). It was assumed that mean within-city gradients of residential population exposure are primarily generated by exposure to air pollution of outdoor origin.

We selected two indoor environments similar in terms of volume and building materials, with virtually identical Air Exchange Rates (AERs). AERs were controlled by installing in each indoor environment a mechanical system to force air to be exchanged between indoors and outdoors. The system consisted of a fan connected to an air pipe (length = 1.2 m) carrying the air to the centre of the room (at a height of 2 m). Increased indoor air pressure caused the flow to go outwards through a grid. The fan velocity in each room was regulated in order to obtain an estimated AER of 0.4 h^{-1} in each room, reflective of a typical level for residential environments (Cattaneo et al., 2011). Our earlier work has shown that this method is highly effective and does not cause significant loss of particles (Zauli Sajani et al., 2015).

The measurements at the two sides of the building were conducted simultaneously indoors and outdoors (i.e. we had four simultaneous measurement sites). Fig. 1 outlines the size of the building and the location of the monitoring sites. Fig. 1S shows a map of the area and gives a bird's eye view of the surroundings of the monitoring sites. The study building was two-storeyed and located next to a street which surrounds the historical centre of Bologna, a 400,000-inhabitant city in northern Italy. Traffic and domestic heating during the cold season are the dominant air pollution sources in the area and cause high levels of air pollutants. In the period 2011–2013 the city-average annual concentration of $PM_{2.5}$ was 19.8 μg/m^3 (average value derived from the two fixed site monitoring stations located in the urban area). The area near the monitoring sites carries a moderate volume of traffic, and the street next to the building is one of the busiest streets of the entire municipal area with a traffic load of 31,000 vehicles (4–5% heavy duty vehicles) each working day. The building is located in a broad (20 m) two-way street canyon. No sources of particles were present in the inner courtyard.

The indoor monitoring site at the front side (from now on “indoor front site”) was on the ground floor (street level). The volume of the room was 119 m^3 with a ceiling height of 3.5 m. The indoor environment at the back (from now on “indoor back site”) was on the ground floor as well. The volume of the room was 61 m^3 and the ceiling height was the same as that at the front side. The two indoor environments were completely separated with no common air exchange. For practical reasons the outdoor $PM_{2.5}$ monitoring site was located next to the building but at about 15 m from the indoor front site along the same street (Fig. 1).

Two monitoring campaigns were conducted in the period June–December 2013. Each monitoring campaign lasted 15 days: 1st campaign from 11 to 25 June (often referred to in the text as “hot period”), 2nd campaign (“cold period”) from 28 November to 13 December. Due to the availability of a unique filter for each day and measuring site, the chemical speciation was performed sequentially every three days for metals, ions, and carbon (Elemental Carbon and Organic Carbon). During cold periods elemental and organic carbon were measured on an 8 h basis in order to avoid filter overload.

2.2. Instrumentation and monitoring procedure

Four identical gravimetric samplers (Skypost PM, TCR TECORA Instruments, Corsico, Milan, Italy) were operated to measure indoor and outdoor daily $PM_{2.5}$ concentrations at the four sites (flow rate 2.3 m^3 h^{-1}). Samples were collected on quartz fibre filters (Whatman, 47 mm diameter) and weighed following the procedure outlined in European Standard EN 12341:2014.